Investigation of effects of surface roughness on coal seam gas transport using a fractal-based lattice Boltzmann method

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SUMMARY

Understanding of gas flow through cleats in coal seams is important for many applications from gas content estimation, production rate assessment and well abandonment. Direct observations of the kinetic process of gas diffusion and adsorption in the cleat-matrix structure through experimental studies are difficult to perform. Therefore, robust numerical simulations are needed for investigations. We present a fundamental study of the microscopic mechanism of gas migration by a numerical model of coal seam gas diffusion and adsorption considering effects of surface roughness to study the effects of rough surfaces on the methane transport.

We found that surface roughness has a significant effect on gas transport by considering fractal dimension ranging from 1.5 to 1.8. Increases of surface roughness enlarge the gas-solid contact area causing higher adsorption capacities which decrease the concentration of gas breakthrough. Results of this work can provide an improved understanding of the effect of microscopic mechanisms of methane migration in coal on the overall reservoir scale.

Key words: Coal seam gas, diffusion and adsorption, lattice Boltzmann method, fractal dimension

INTRODUCTION

Coal seam gas (CSG), as one of the unconventional resources, is stored in a low porosity/permeability reservoir which causes challenges for production (Busch and Gensterblum, 2011; Moore, 2012). The production of CSG is largely affected by topological structures of coal which consist micropores within the matrix and macro fractures, so-called cleats (Laubach *et al.*, 1998). The mechanism of microscale gas transport through so-called coal cleats which form a network of micro-channels/fractures for gas transfer is an attractive spot for many scientists from many fields such as microstructural characterization (Mostaghimi *et al.*, 2017), diffusion (Naveen *et al.*, 2017), adsorption (Mayo *et al.*, 2018) and adsorption-induced deformation(Chen, 2012) studies. The gas flow is mainly supported by the cleat network for which the surface roughness is very significant throughout gas transport. Roughness plays an important role because the coal surface is very attractive to methane molecules. Direct studies on the effects of surface roughness for methane migration in coal by experimental methods are difficult to perform because the micro-scale heterogeneous pore structure and methane sorption properties are difficult to observe. Therefore, robust numerical simulations are good supplements for investigations. In this paper, a numerical model of coal seam gas diffusion and adsorption considering surface roughness is developed with a fractal-based lattice Boltzmann method.

METHOD AND RESULTS

Studies of the CSG flow in coal are conventionally carried out upon ideal parallel smooth fractures (Snow, 1969). Nowadays, the application of new imaging technologies allows digitalized characterization of complex porous structures, such as coal (Drazer and Koplik, 2000; Jing *et al.*, 2017; Madadi and Sahimi, 2003). In this work, the rough cleat surface of coal is characterized by a 3D-Laser profiler and the surface roughness is quantified by the fractal dimension. Generic variants of the rough profiles are generated by using the Weierstrass-Mandelbrot function through altering the fractal dimension D and length-scale parameter G. The schematic diagram of the coal-cleat surface characterization and reconstruction is illustrated in Figure 1. The fractal-based lattice Boltzmann method is introduced to solve the governing equations for the gas flow and diffusion processes.

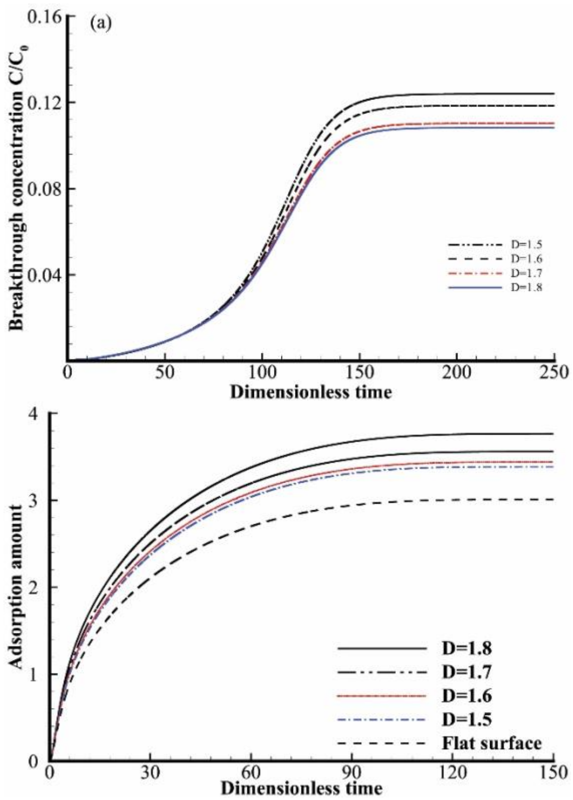

Figure 2. Partial results of investigations of the methane transport in a rough cleat for various D. (a) Breakthrough curves; (b) Adsorption curve.

The results are presented in Figure 2. It is found that the fractal dimension D has a slight effect on the gas velocity but a significant effect on the gas diffusion. The gas velocity decreases as D increases by affecting the contact area. The results show good agreements with the published data in the literature (Cai *et al.*, 2013; Deng *et al.*, 2016; Dierich and Nikrityuk, 2013) where it also reported that the effects of surface roughness increase for higher Knudsen and Reynolds numbers. Results of this work provide a quantified way of studying the effects of microstructural properties on the methane transport with numerical methods and give an improved understanding of the mechanism of the CSG production in coal on the overall reservoir scale.

CONCLUSIONS

We have presented a numerical model aimed to understand the mode of the methane diffusion-adsorption process by the investigation of the effects of microstructural properties of coal on the CSG transport using a fractal-based lattice Boltzmann method. We found that surface roughness quantified by fractal dimension plays an important role in the methane diffusion and adsorption by affecting the contacting area which agrees with the previous research. This is achieved by constructing a generic model of a rough-surface cleat with numerical method, considering dynamic processes of gas flow, diffusion and adsorption.

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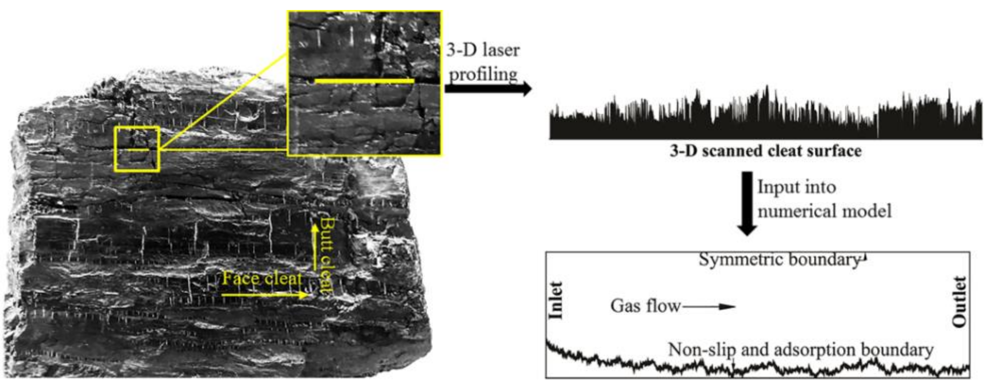

Figure 1. Procedures of 3-D image analysis and construction of a numerical model based on the scanned rough cleat surface.